Response to Reviewer#2

Review of 'Identifying the seeding signature in cloud particles from hydrometeor residuals' Konwar et al. AMT-2023-171

This is a second review following my first review of the initially submitted manuscript. As stated in my initial review, I believe this work makes an important contribution and is worthy of publication. However, I also noted several major points that the authors needed to address prior to publication. Unfortunately, I do not feel my points have been addressed adequately in the revised manuscript and/or in the 'response to reviewer' comments. For this reason, I recommend rejecting the manuscript at this time.

Below I point to specific comments in my original review and describe how/why I believe the authors response was not adequate in many cases.

Response: The authors never intended to ignore the suggestions provided by the esteemed reviewer. The constructive comments helped immensely to improve the quality of the manuscript. Below are the clarifications given as a response to the points raised by the reviewer.

In my summary review, second paragraph, I noted that I did not understand why all of the regions downwind appeared to have elevated K and Cl. The authors responded by noting that my original interpretation was incorrect and revised Figure 5 to illustrate elevated levels were only sampled at discrete locations. This was an excellent answer an explanation to my original question

Response: We think there is a misunderstanding; we never questioned the reviewer's suggestion. We in fact (as suggested by the reviewer) used a simple advection model to understand the locations of the seeding particlesin the downwind direction.Accordingly**,** the texts and figures were revised. However, since this study did not consist of a component with numerical simulation, we did not include the advection model results in the manuscript but did so in the response to the reviewer. In the revised manuscript, we have included a discussion on the advection of the plumes in the slanted downwind direction. Advection of seeding plumes as reported from CAIPEEX experiment (Gayatri et al., 2023) and the SNOWIE field program (Xue et al., 2022) is now discussed in the revised manuscript. Gayatri et al., 2023 illustrated the seeding impact downwind of the seeded area through the high-resolution numerical model in the same monsoon environment with the monsoon low-level jet (LLJ) as detailed in the present study. The cloud bases are situated very close to the region with high wind speeds in the monsoon low-level jet and the advection of seeding plume downwind of the seeded location is noted. However, the fact that seeding was done specifically in the strong updraft zones and the seed particles were also lifted inside the cloud and more cloud droplets were noted both in the observations and simulations. The clouds selected for seeding had higher liquid water content (Prabhakaran et al., 2023).

Reference:

Gayatri K, Prabhakaran T., Malap N., Konwar M., Gurnule D., Bankar S., Murugavel P. Physical evaluation of hygroscopic cloud seeding in convective clouds using in situ observations and numerical simulations during CAIPEEX, (2023), *Atmospheric Research*, 284: 106558, March 2023, DOI:10.1016/j.atmosres.2022.106558, 1-17

Prabhakaran T., Murugavel P., Konwar M., Malap N., Gayatri K., Dixit S., Samanta S., Chowdhuri S., Bera S., Varghese M., Jaya Rao Y., Sandeep J., Safai P.D., Sahai A.K., Axisa D., Karipot A., Baumgardner D., Werden B., Fortner E., Hibert K., Nair S., Bankar S., Gurnule D., Todekar K., Jose J., Jayachandran V., Soyam P.S., Gupta A., Choudhary H., Aravindhavel A., Kantipudi S.B., Pradeepkumar P., Krishnan R., Nandakumar K., DeCarlo P.F., Worsnop D., Bhat G.S., Rajeevan M., Nanjundiah R., CAIPEEX - Indian cloud seeding scientific experiment, *Bulletin of the American Meteorological Society*, 104, November 2023, DOI:10.1175/BAMS-D-21-0291.1, E2095–E2120

Xue L., C. Weeks, S. Chen, S. A. Tessendorf, R. M. Rasmussen, K. Ikeda, B. Kosovic, D. Behringer, J. R. French, K. Friedrich, T. J. Zaremba, R. M. Rauber, C. P. Lackner, B. Geerts, D. Blestrud, M. Kunkel, N. Dawson, and S. Parkinson (2022), Comparison between Observed and Simulated AgI Seeding Impacts in a Well-Observed Case from the SNOWIE Field Program
Journal of Applied Meteorology and Climatology, page345–367, https://doi.org/10.1175/JAMC-D-21-0103.1

In the last two sentences of the third paragraph of my summary review, I asked the following questions: “I also wonder, since the same aircraft is used for releasing seeing material and making measurements; is there any potential for contamination? Were any experiments conducted where NSCl was re-sampled upwind following the release of seeding material?” The authors responded:

“We could sample the seeding clouds downwind, after the dispersal of seeding agents in the cloud. Since the stratus cloud usually covers a large area, assuming spatial uniformity in the cloud properties, the measurement of the seeded clouds appears un-contaminated due to the transect made by the aircraft.”

This does not answer the question(s) asked. Also, the authors state they can ‘assume spatial uniformity’ in cloud properties, but the LWC color plot in Fig 5a clearly indicates a lot of heteorogeneity, even in regions with no elevated K or Cl. Also, in the new Fig 5, there is clearly a small area of elevated K and Cl prior to seeding release. The authors should explain that.

Response: We apologize for this oversight. The aircraft could indeed release non-volatile and fine aerosol particles through exhaust emissions (Anderson et al., 1998), which may also contaminate the cloud mass. Further, Prabhakaran et al. (2023) also compared flare size distribution with the background and aircraft exhaust aerosol size distributions (see, supplementary material https://doi.org/10.1175/BAMS-D-21-0291.2). That study indicates the potential impact of aircraft exhaust on the ambient aerosol size distributions that might alter mean radius and number concentrations with different modes of log-normal size distributions. A similar discussion is now added in the revised manuscript, please see page 18.

The reviewer is correct in pointing out the heterogeneity (did not mention in the manuscript) of the cloud structure. This oversight on the cloud structure has been corrected.

The reviewer is also correct in pointing out a small area of elevated K and Cl, prior to the flare burning. This was measured outside the cloudy. It might be appeared probably due to other unknown sources. Now the same is mentioned in the figure caption.

Under Major Comments

#1 – I suggested that the authors could strengthen the introduction by noting that previous tracer technologies used to identify seeded regions were unable to determine if the seeded material actually makes it into hydrometeors. (This new methodology does just that!). The authors responded:

"Thank you for the valuable suggestion. Now a few sentences are added emphasizing the limitation of past techniques."

However, I could not find where this had been added. If the author's had provided a revised manuscript with changes tracked (or even provided the new text in their response) it would have been helpful.

Response: We apologize for the confusion. The sentence 'Using these tracers as proxies for tracking air masses carrying seeding material is limited by the challenge of unambiguously connecting their presence with the seeding material due to their non-reactive nature with cloud particles.' Now it is added in the introduction section. For reference, now it is highlighted with red color in the track changed version of the manuscript. Please see L72-74, page 3-4.

#3 I asked the question, that if the authors wanted to ensure they were in the 'core' of the cloud why use LWC_max instead of LWC_ad? The author response (not copied here for brevity) stated that the goal was to select 'core' regions of the transect, noting (correctly) that measured LWC is always less than adiabatic values due to entrainment and mixing. They went on to state that in the present study ratios of max to adiabatic varied between 13 to 96%. I would suggest, that if they included regions of cloud in this study in which the maximum LWC was only 13% of adiabatic, than changes in cloud microstructure would be strongly influenced by processes such as entrainment and mixing. It is incumbent on the authors to prove that changes/differences in microstructure between seeded and non-seeded clouds are the result of seeding and not some other (natural) process.

Response: The revised figures include ranges of LWC adiabatic fractions, along with the LWC/LWC_{max} ranges. In addition, we have included descriptions highlighting the impact of the entrainment and mixing process on our results. We also noted that the adiabatic fraction values could be highly variable near the clouds base. For example near the cloud base, the LWC values are quite small, e.g. <1 g m^{-3}, a small change in the measured LWC values could yield a large change in adiabatic fraction (AF). Other aspects, for example, the effect of seeding particles on the LWC profiles may also affect the AF, the effect of drizzle formation in the cloud can decrease AF are discussed in the manuscript. Please refer to page 7-8, L 160-163 of the revised manuscript (please see the track changed version).

An example of the variation of LWC non-seeded cloud (NSCl), seeded clouds (SCl) and adiabatic LWC (LWC_{ad}) with respect to the distance from the cloud base (D*, km) is shown in the figure below.The case considered is for 23rd August 2019. The LWC for NSCl and SCl cases are calculated in the size range of 3-50 µm.It can be seen that the LWC values of both NSCl and SCl are smaller than the LWC_{ad} values at all D*. Two SCl cloud passes near the cloud base were less diluted; however, uncertainty remains as the release of seeding materials may activate new cloud droplets and change the LWC values. At higher D*, LWC values are quite small as cloud droplets convert into drizzle drops.

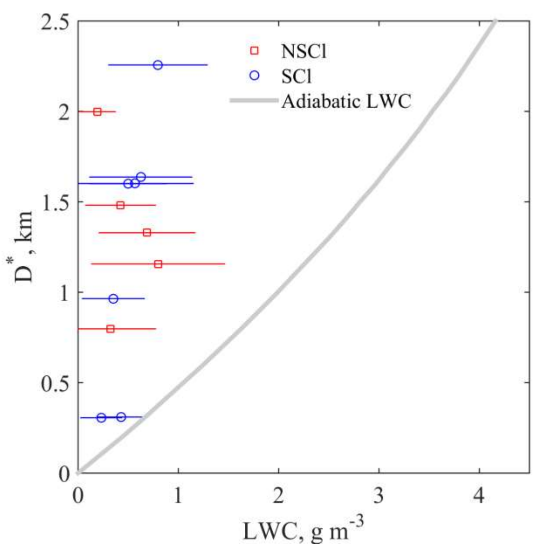

Figure: Case 23rd August 2019. Profile of non-seeded cloud (NSCl) LWC and seeded cloud (SCl) LWC are shown with respect to the distance from the cloud base (D*, km). Standard deviations from the mean values are also shown.

#4 I asked the question(s) at the end of the comment: LWCs are generally higher after seeding (although the measurements are lower in cloud)…why? Seeding should not result in increased condensed water, but rather just changes in how the condensed water is distributed….etc. The authors response did not address this question.

Response: We respectfully disagree with the reviewer that seeding cannot increase the LWC. Seeding will not change the adiabatic LWC, i.e. the potentially available LWC, however, by activating new droplets, this does increase the LWC because these new droplets have now converted the available water vapor into liquid water. Since these clouds under consideration are convective in nature and there are significant changes in LWC also due to entrainment and evaporation effects. Several of our previous studies (Prabha et al., 2011; Patade et al., 2015; 2019) have illustrated that more aerosols in the sub-cloud layer can increase LWC with height.

Reference:

Patade, S., Kulkarni, G., Patade, S., Deshmukh, A., Dangat, P., Axisa, D., Prabha, T. V.: Role of liquid phase in the development of ice phase in monsoon clouds: Aircraft observations and numerical simulations. Atmos. Res., 229, 157–174, 2019. https://doi.org/10.1016/j.atmosres.2019.06.022

Patade, S., Prabha, T. V., Axisa, D., Gayatri, K., Heymsfield, A,: Particle size distribution properties in mixed-phase monsoon clouds from in situ measurements during CAIPEEX Jour. of Geophys. Res. Atmos., 120, 19, 2015.

#6 I asked roughly the same question as in #4, except for seeding case iii. The authors responded describing why Nt might be different and discussed the role of updraft; all of which I agree with, but disregards the question completely.

Response: Please see our response to comment #4. These are illustrated in the revised manuscript.